U.S. MAGNET DEVELOPMENT PROGRAM

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Wire and Cable Characterization of Nb_3Sn Conductor with High Heat Capacity

September 25, 2019

Emanuela Barzi, Fabrizio Berritta, Daniele Turrioni, Alexander Zlobin

US Magnet Development Program

U.S. MAGNET DEVELOPMENT PROGRAM

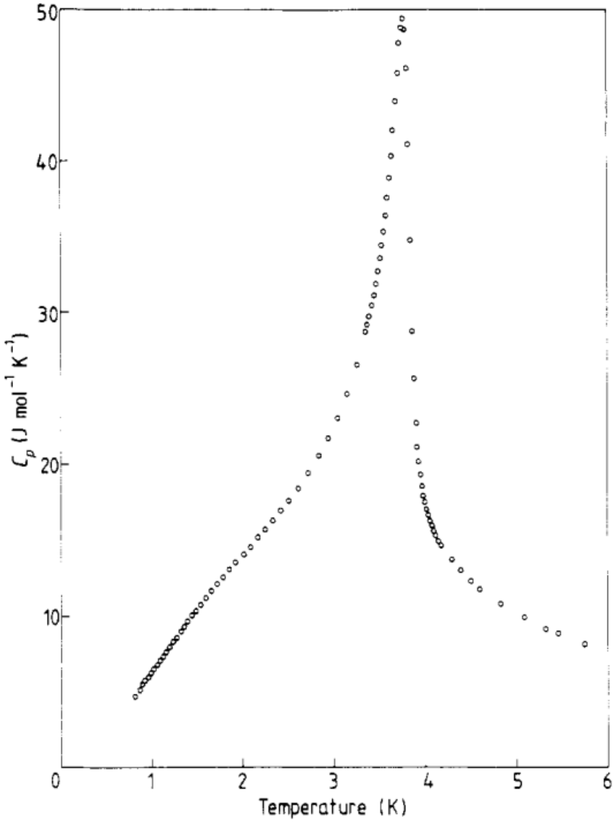
Outline

- Reduce magnet training by increasing Nb_3Sn wire specific heat, i.e. replace some elements in wire with Gd_2O_3 /Cu tubes.
- Worked with industry to produce wire prototypes
- Help achieve goals with Finite Element models, including:

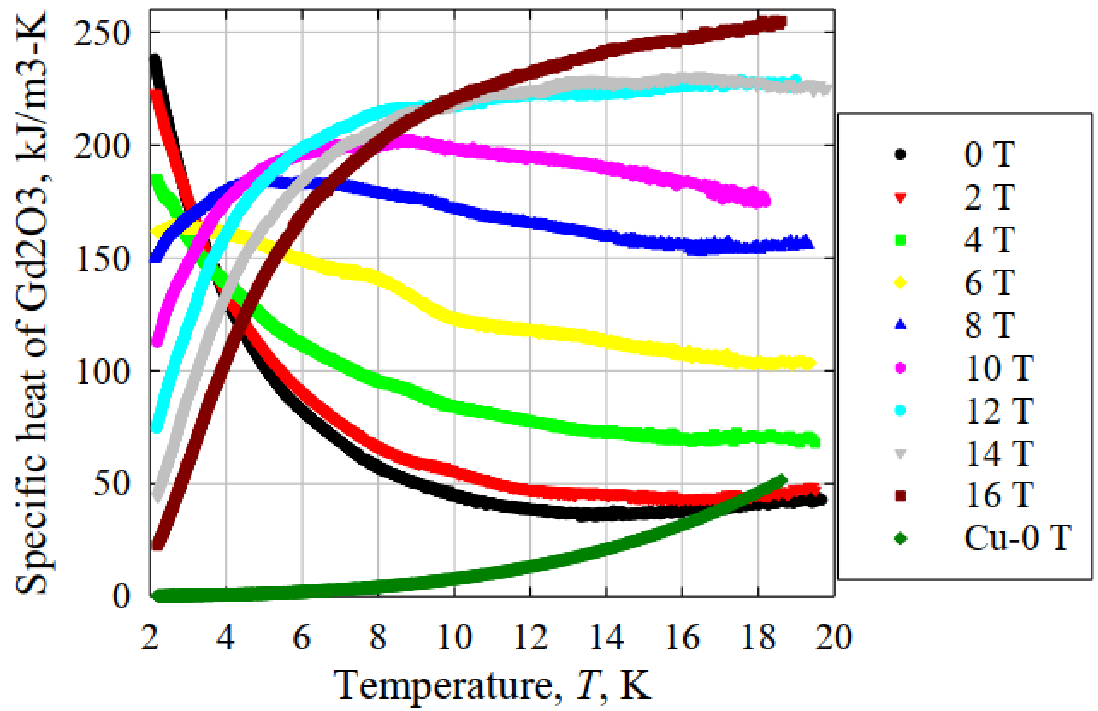
1. High-C_p tube location to optimize thermal efficiency
2. High-C_p tube location for drawability/ fabricability

- Study model sensitivity
- Compare with data
- Conclusions

Heat Capacity of Gd_2O_3



Specific heat of monoclinic Gd_2O_3 R. Hill et al 1983 J. Phys. C: Solid State Phys. 16 2871

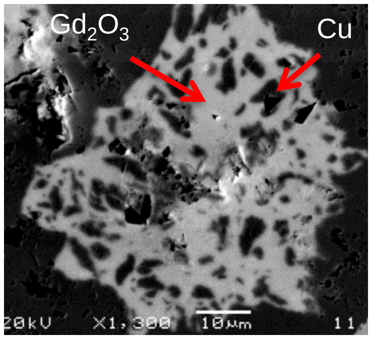


X. Xu, A. V. Zlobin, E. Barzi – Fermilab; C. Buehler, M. Field, B. Sailer, M. Wanior, H. Miao – Bruker EST; C. Tarantini – Florida State University.

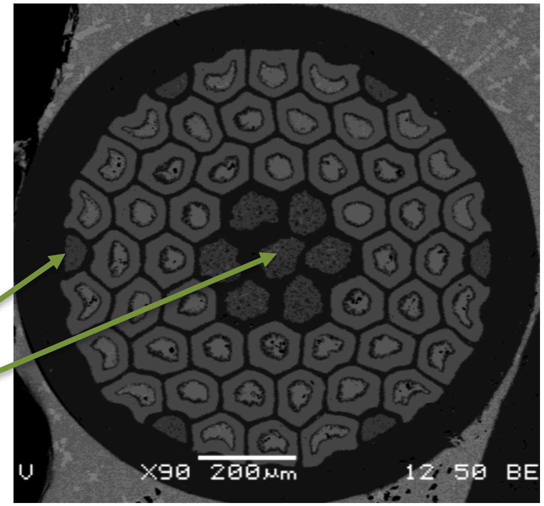
"Enhancing specific heat of Nb_3Sn conductors to improve stability and reduce training. "

Presented at CEC-ICMC 2019

Industry Produced Nb_3Sn Wires



Tin in Tube wire

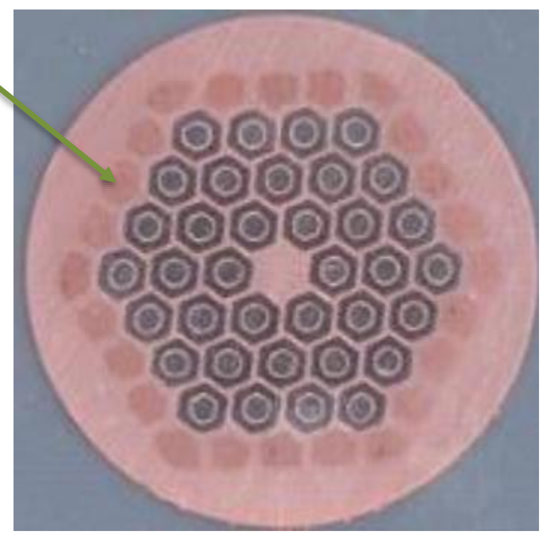


Internally and on Corners

Hypertech

X. Xu, P. Li, A. Zlobin and X. Peng, *IEEE Trans. Appl. Supercond.*, vol. 23, Art. no. 4001605, 2018

Gd_2O_3/ Cu tubes

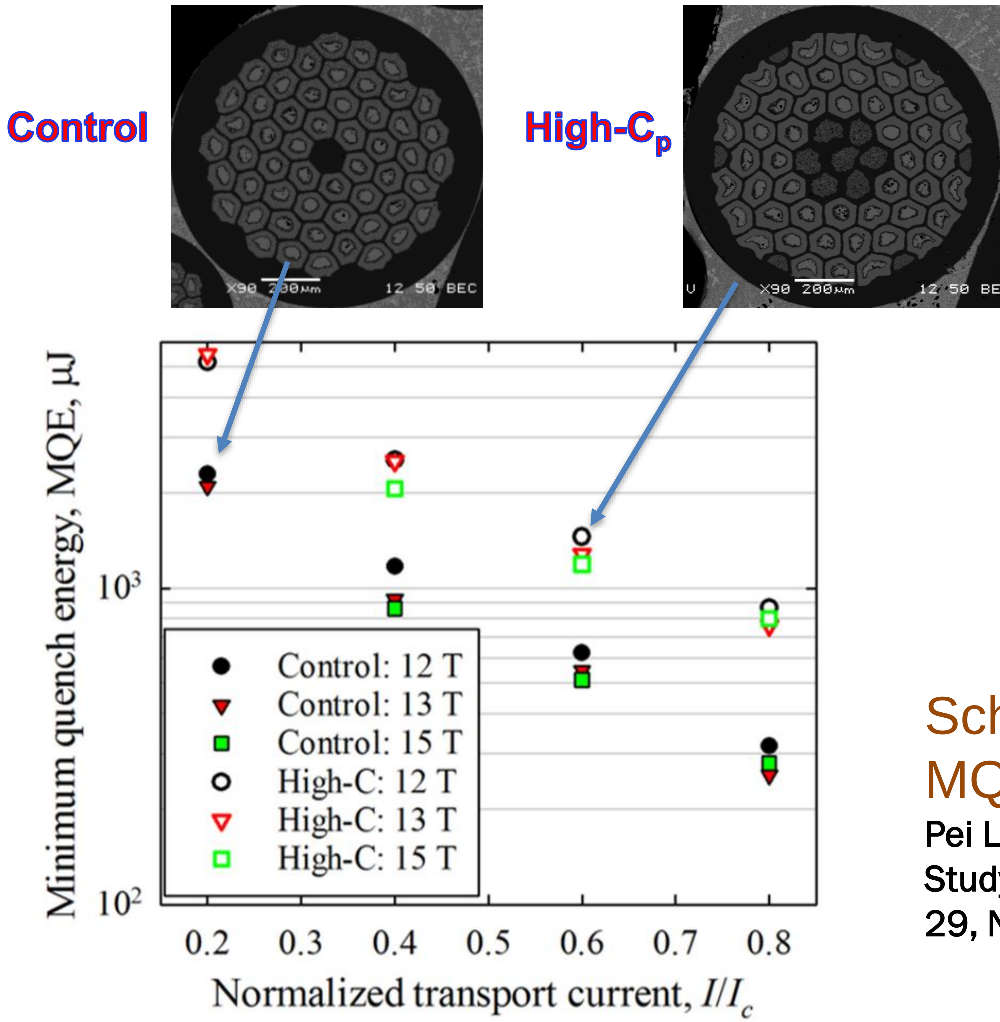


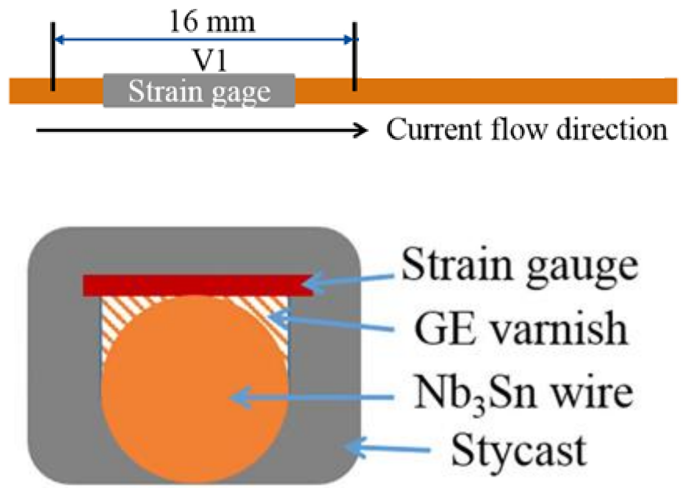
Restacked Rod Process wire

Externally

Bruker-OST, 2019

Minimum Quench Energy Measurements

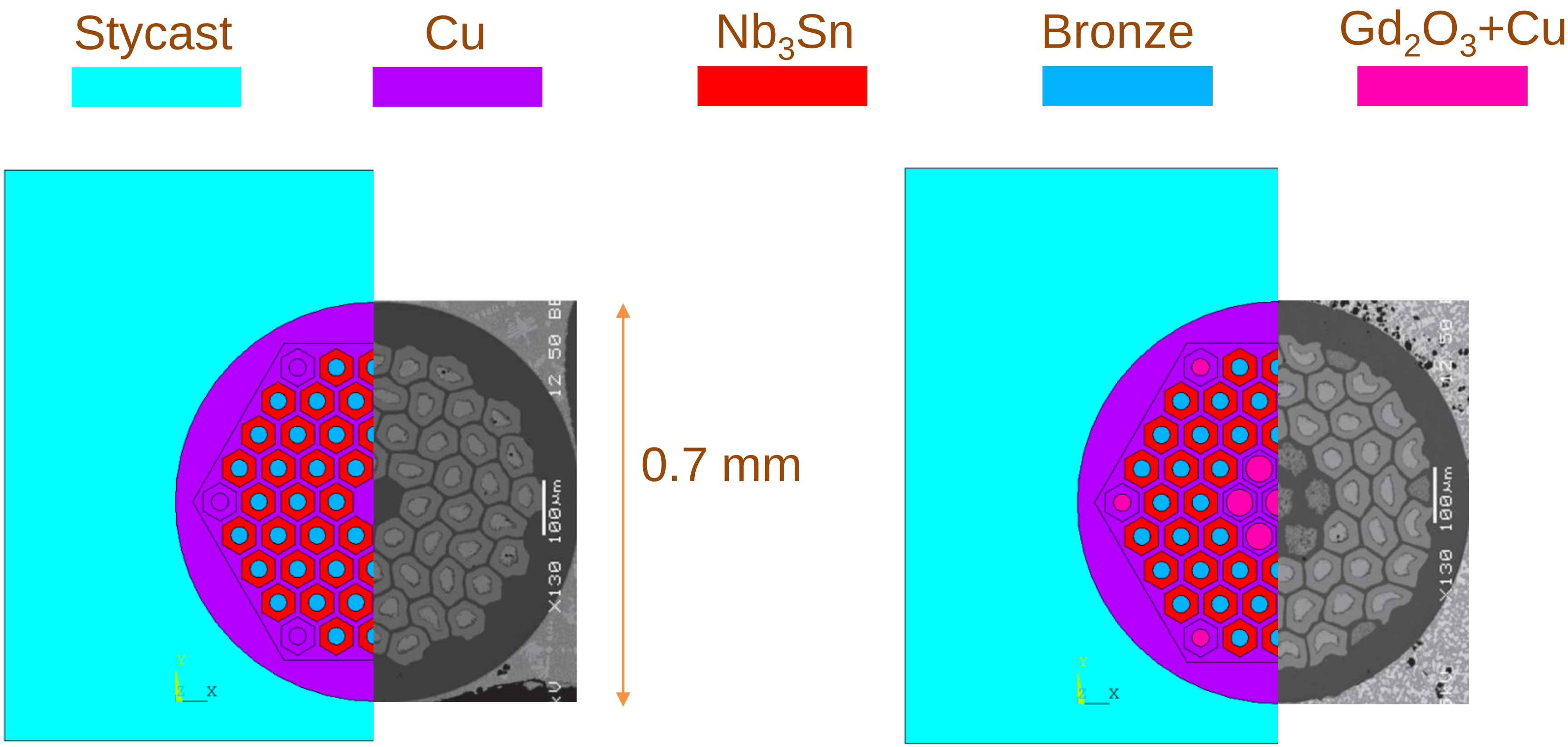




Schematics of the setup to measure MQE.

Pei Li, Xinchen Xu, and A. V. Zlobin, “Development and Study of Nb_3Sn Wires With High Specific Heat.” IEEE, VOL. 29, NO. 5, 2019

ANSYS Thermal APDL Model



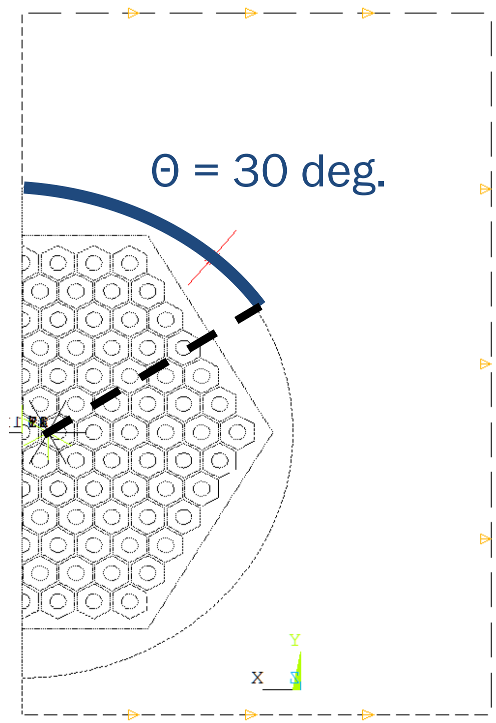
"Measurements and modelling of mechanical properties of Nb_3Sn strands, cables and coils", E. Barzi, et al., IEEE Trans. Appl. Supercond., vol. 29, no. 5, Art. no. 8401808, 2019.

Thermal Model Hypotheses

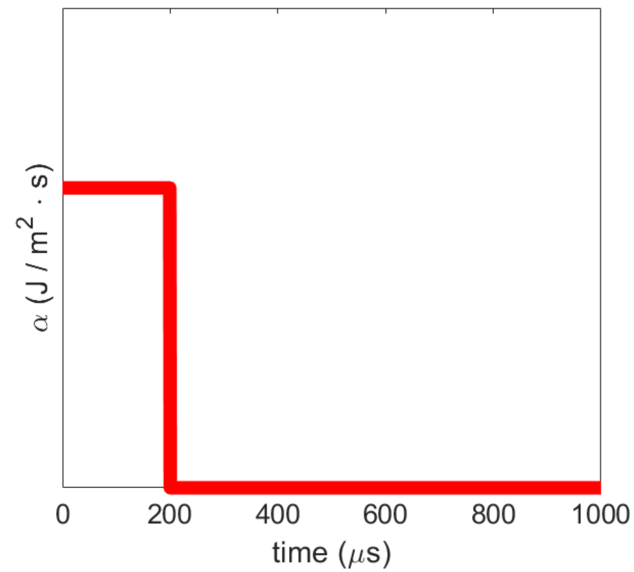
The initial temperature is 4.2 K and it is set as boundary temperature constraints:

- $T(\mathbf{r},0) = 4.2$ K
- $T(\mathbf{r},t) = 4.2$ K @boundary

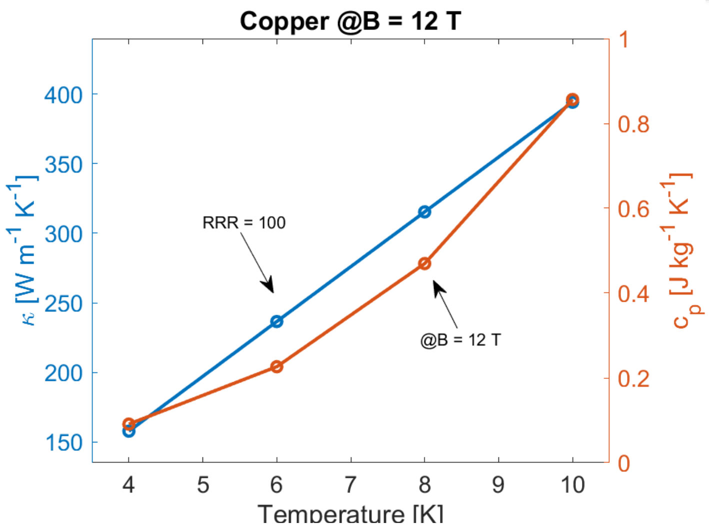
Magnetic Field B=12T

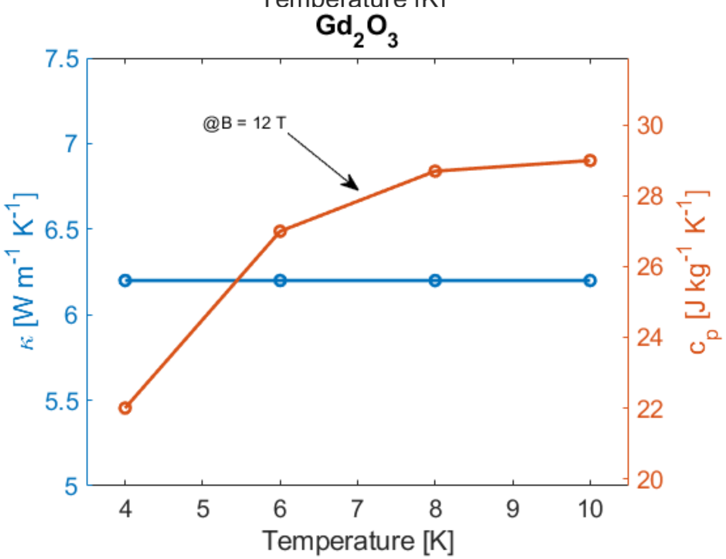


An heat flux pulse of 200 µs is applied on the upper half arc (2D model) with unitary thickness.



Temperature/Field Dependent Material Properties



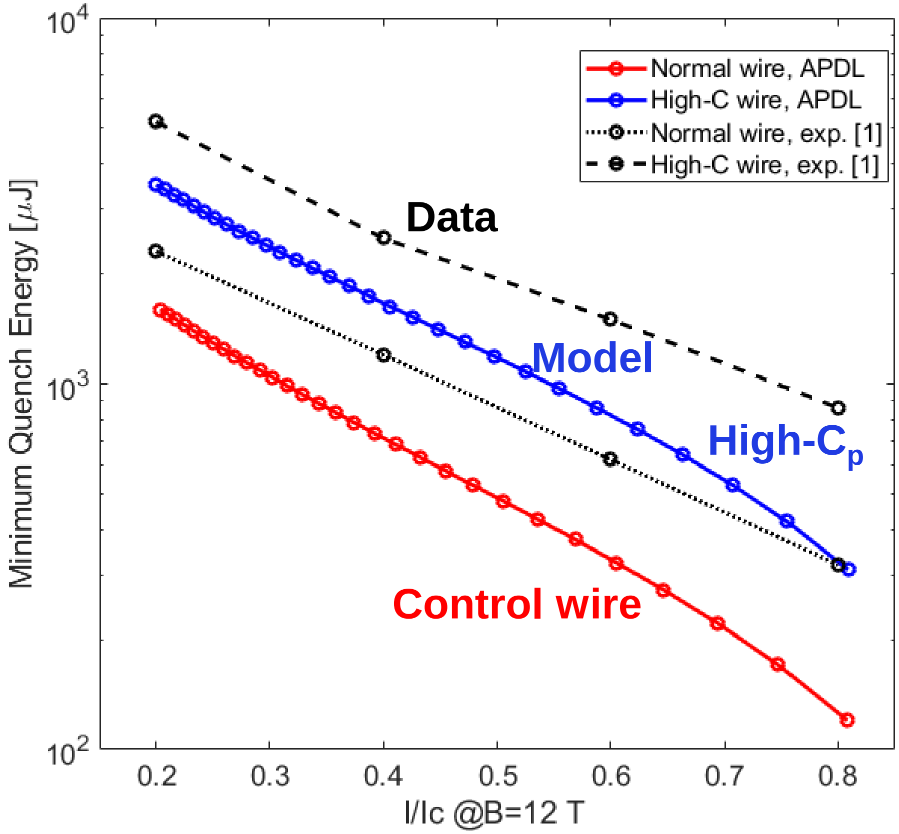


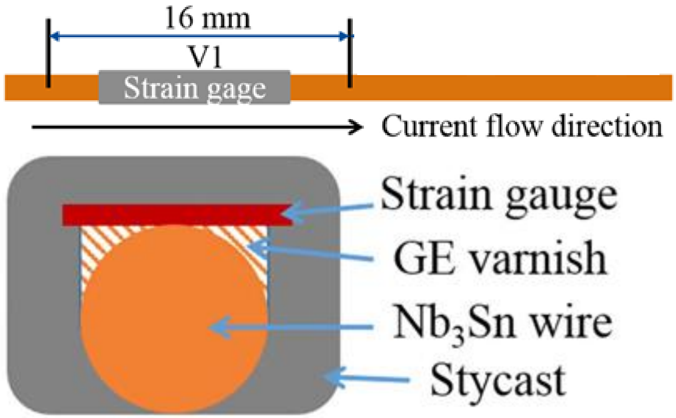
By obtaining I_c(12 T, 4.2 K) using parameterization and solving for T_c in I_c(12 T, T_c) the following critical temperatures:

Current ratio I/I_c @B=12 T	T_c
0.2	6.3 K
0.4	5.3 K
0.6	4.8 K
0.8	4.4 K

Sensitivity of MQE from model was calculated for thermal conductivity and heat capacity variations of Nb_3Sn, Cu, Gd_2O_3, stycast and bronze.

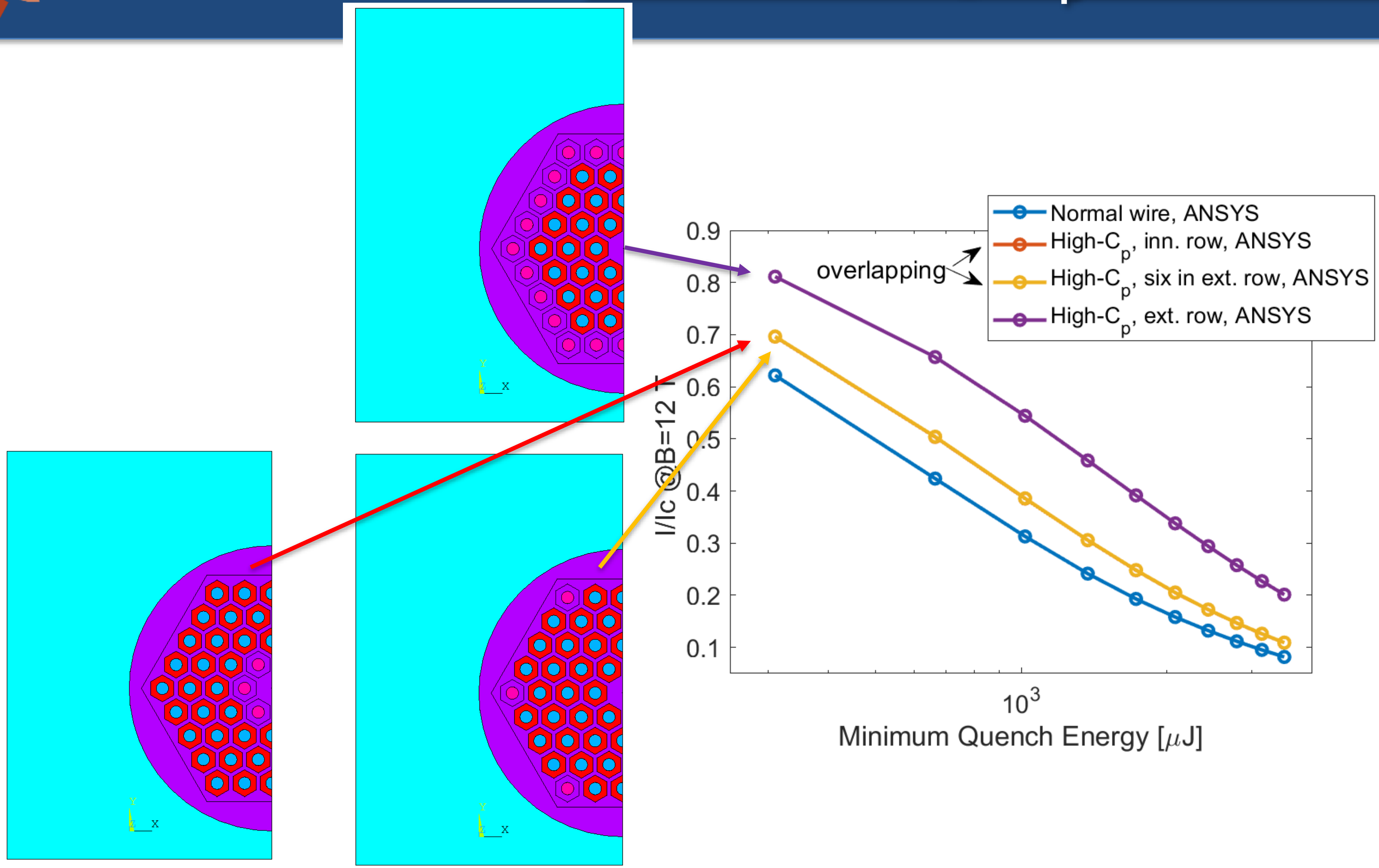
Model versus Experiment





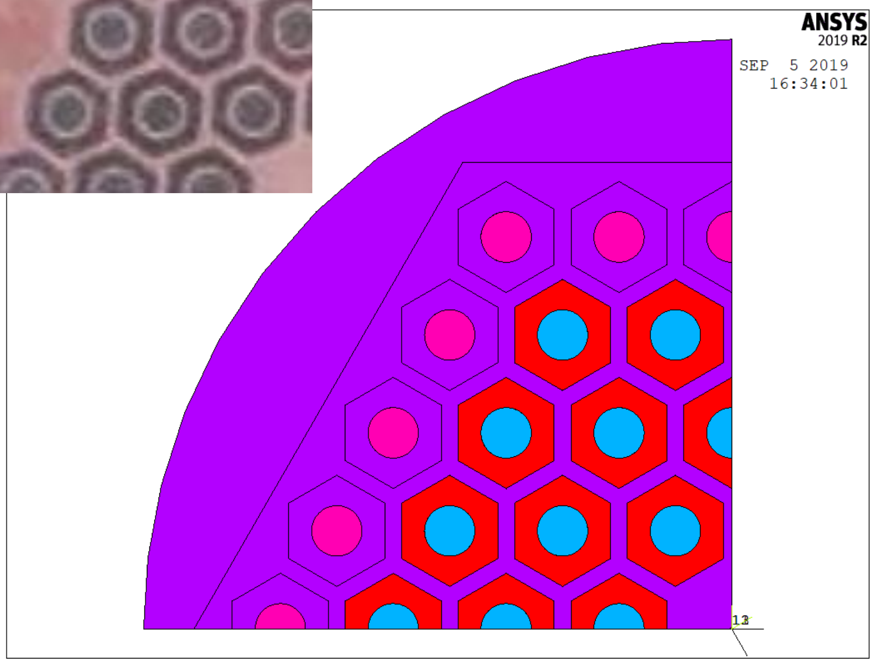
MQE from model is lower than MQE from data since in the experiment 100% of the heat from the heater is assumed to go into the sample.

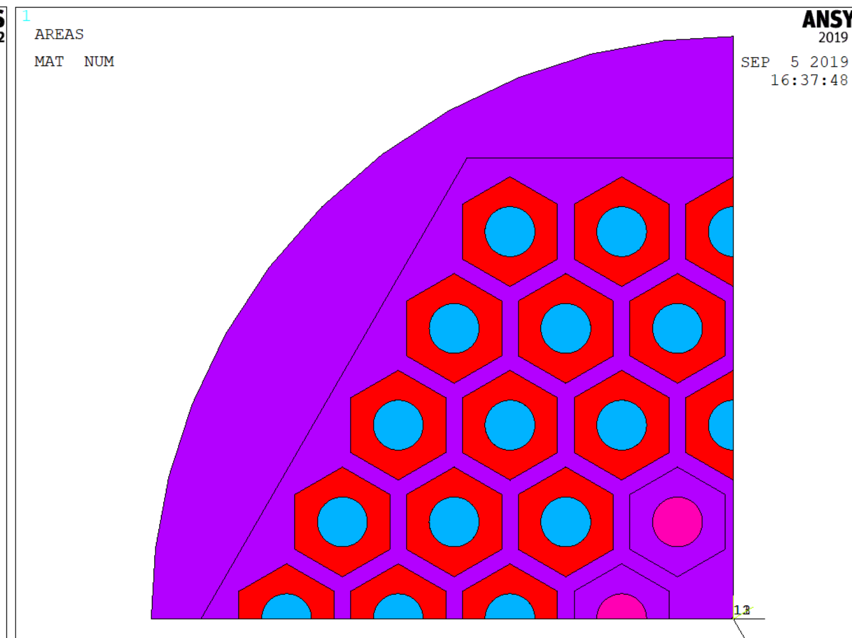
Is there an optimal thermal location for high-C_p elements?



Mechanical ANSYS Plastic Model

Nb-Sn-Cu Composite (pre-reaction)





High-C_p elements in the <u>outermost</u> row

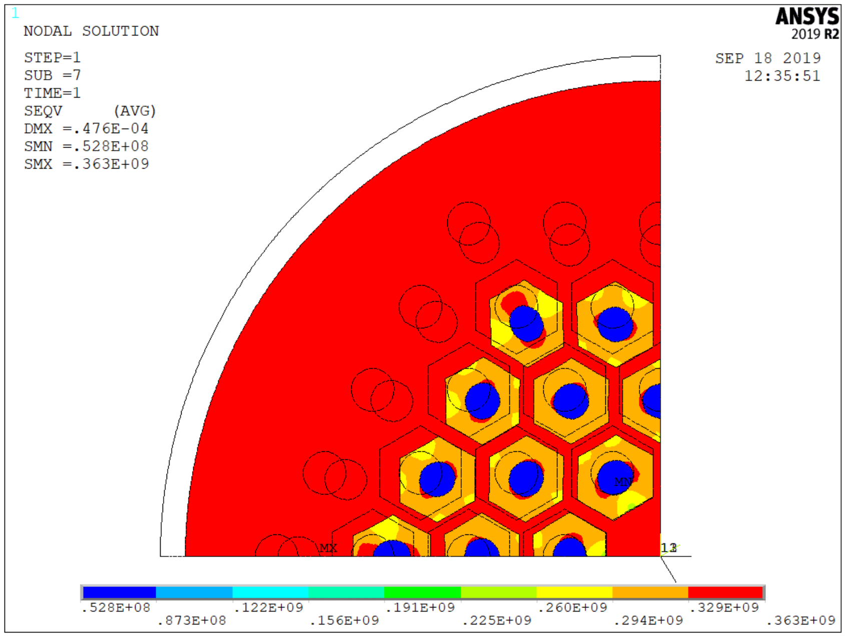
Actual Bruker-OST Wire

High-C_p elements in the <u>innermost</u> row

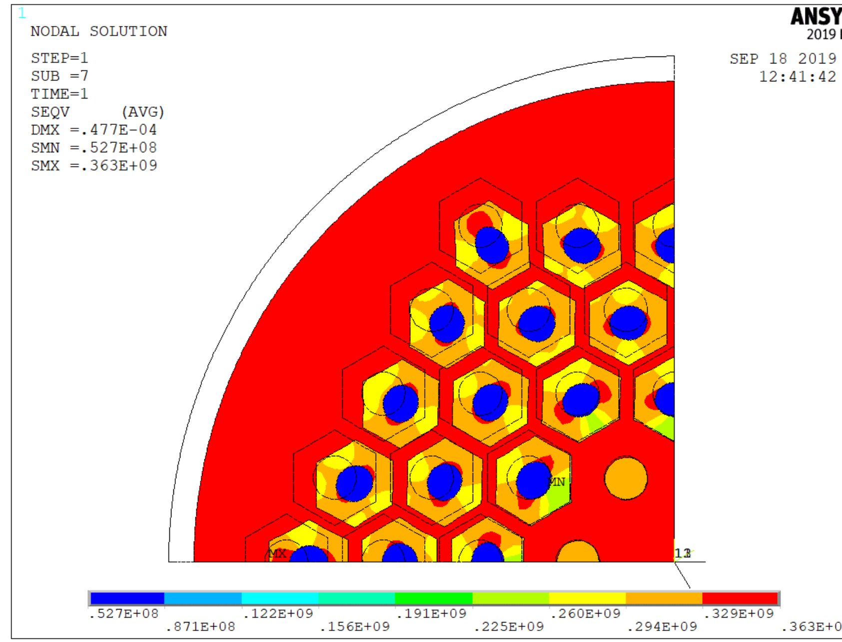
Virtual design

Simulation of Wire Drawing Step

5% true strain



Von Mises Stress, 5% strain



Von Mises Stress, 5% strain

Work in progress, other material properties are being looked at to best represent drawing damage and confirm that for fabricability the location of the Gd_2O_3 tubes might be critical for success.

Conclusions

- The FEM thermal models accurately reproduce relative behavior in Minimum Quench Energy between regular and high-C_p wires.
- They were also very useful in contrasting the intuitive thought that for maximum efficiency the Gd_2O_3 tubes have to be external to the superconducting elements.
- This is good news since on the contrary there are indications that placing the Gd_2O_3 tubes externally hinders drawing.
- FEM structural models have been developed to aid in the design of architectures that can be realized without drawing failure. Further analyses are required to find the right criteria.
- More MQE measurements will be performed on both regular and high-C_p wires.

Thank you for your attention.